

Gamma-ray properties of globular clusters and the “fundamental planes”

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We report on the discovery of gamma-ray emission from several globular clusters (GCs), including Terzan 5, the second known gamma-ray GCs. By now, more than a dozen GCs are known to emit gamma-rays of energies above 100 MeV, thus enabling us to carry out the first detailed correlation study with several cluster properties. We found strong correlations between the observed gamma-ray luminosities and four cluster parameters: stellar encounter rate, metallicity [Fe/H], and energy densities of the soft photons at the cluster locations. These “fundamental planes” of gamma-ray GCs put an intimate relation of the observed gamma-rays to the underlying millisecond pulsar population and have important implications on the origin of the gamma-ray emission of GCs.

I. INTRODUCTION

Radio and X-ray observations have revealed about 140 millisecond pulsars (MSPs) in 26 globular clusters [GCs; 1]. However, the presence of much stronger X-ray emitters can contaminate the X-ray observations of MSPs. Because MSPs are the only known steady γ -ray sources in GCs [2], γ -ray observations of GCs serve as an alternative channel in studying the underlying MSP populations in GCs.

Using the Large Area Telescope (LAT), γ -rays from 8 GCs [3] have been discovered, including 47 Tucanae [4] and Terzan 5 [5].

II. MODELS OF γ -RAYS FROM GLOBULAR CLUSTERS

The radiation mechanism of γ -rays is unclear. In the pulsar magnetosphere model, e.g. [6], γ -rays up to a few GeV come from the MSPs through curvature radiation. On the other hand, inverse Compton (IC) processes resulted from energetic particles up-scattering low-energy photons, such as starlight and infrared light, may give rise to γ -rays of MeV to TeV energies, e.g. [7]. In either model, it is expected that the γ -ray luminosity of a GC is proportional to the stellar encounter rate, a measure of the number of MSPs in a GC.

III. NEW γ -RAY GLOBULAR CLUSTERS UNCOVERED

Terzan 5 contains the largest number of known MSPs among all GCs. It was discovered as the second known γ -ray emitting GC after 47 Tucanae [5]

(see Figure 1). We note that 47 Tucanae was discovered in the bright source list [8], while the discovery of Terzan 5 in γ -rays was announced [5] before the release of the first Fermi/LAT catalog [9] and the report of the 8 GCs [3].

Like 47 Tucanae, the γ -ray spectrum of Terzan 5 also shows a cutoff at ~ 3 GeV [3, 5]. After the discovery of other six γ -ray emitting GCs [3], we also identified a group of GCs with high encounter rate. Using more than two years of data taken from LAT, we found γ -ray emission from the directions of Liller 1, NGC 6624, and NGC 6752 [10]. The test-statistic maps of the regions around these 3 GCs are shown in Figures 2 and 3. For M80, NGC 6139, and NGC 6541, the detection is marginal ($4 - 5\sigma$) when it was first reported [10].

For the cases where the γ -ray emission is offset from the core (i.e. Liller 1 and NGC 6624), the γ -ray spectra in the energy range of 200 MeV to 100 GeV are presented in Figure 4. The photons above ~ 20 GeV are detected at significance levels of 3–4. Once the existence of these high-energy photons is established, it will be easier to be reconciled in the IC models than in the pulsar magnetosphere model. In the latter case, spectral cut-offs at several GeV are expected.

IV. THE FUNDAMENTAL PLANES OF γ -RAY GLOBULAR CLUSTERS

We have investigated the properties of the γ -ray emitting globular clusters [11]. By correlating the observed γ -ray luminosities with various cluster properties, we probe the origin of the high energy photons from these GCs. We found that the γ -ray luminosity is positively correlated with the encounter rate and the metallicity [Fe/H] which places an intimate link

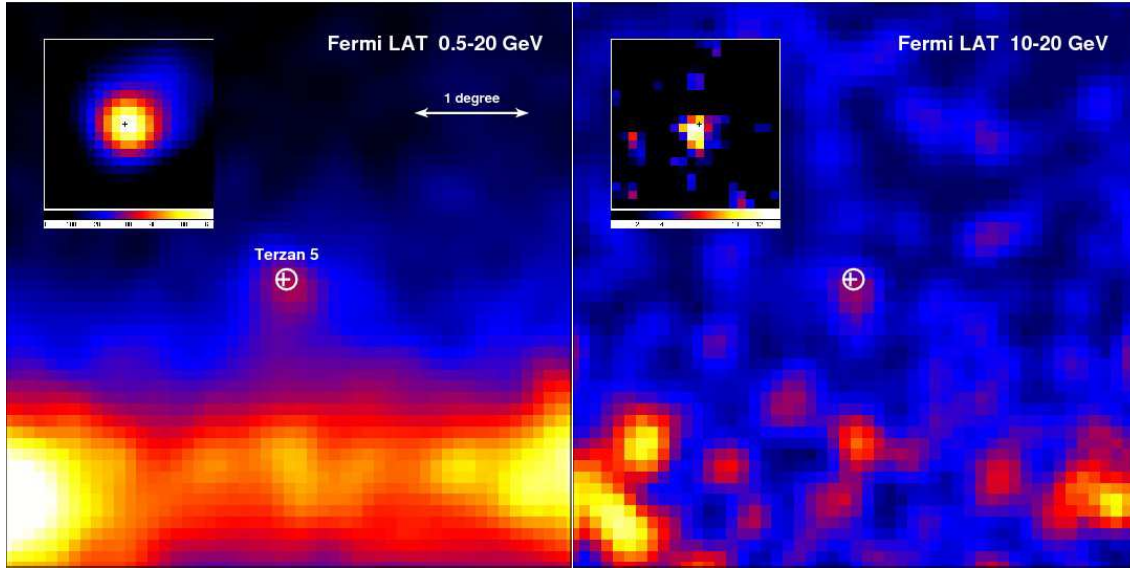


FIG. 1: The count maps of the $5^\circ \times 5^\circ$ region centered on Terzan 5. The insets show the test-statistic maps [5].

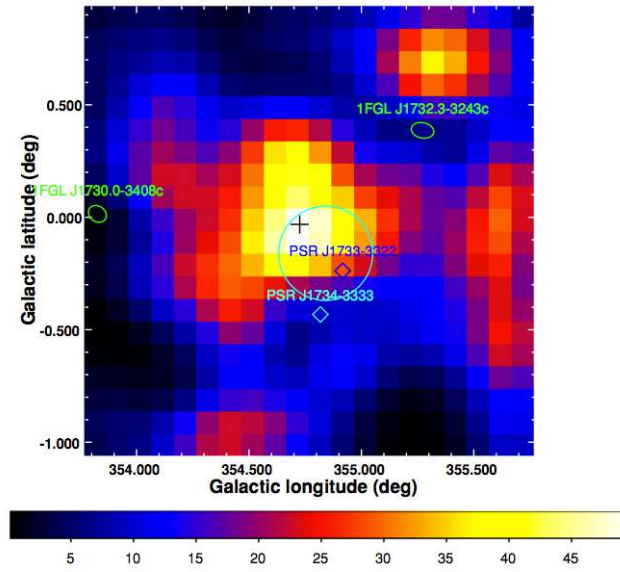


FIG. 2: The test-statistics map of Liller 1 [10]

between the γ -ray emission and the MSP population. We also found that the γ -ray luminosity increases with the energy densities of the soft photons at the cluster location. When combining two parameters at the same time, the correlation is even stronger. The edge-on fundamental plane relations of γ -ray GCs are depicted in Figure 5.

This finding strongly suggests that models that incorporate optical or infrared photons should be taken into considerations in explaining the γ -ray emission from GCs, e.g. the IC models [7].

Acknowledgments

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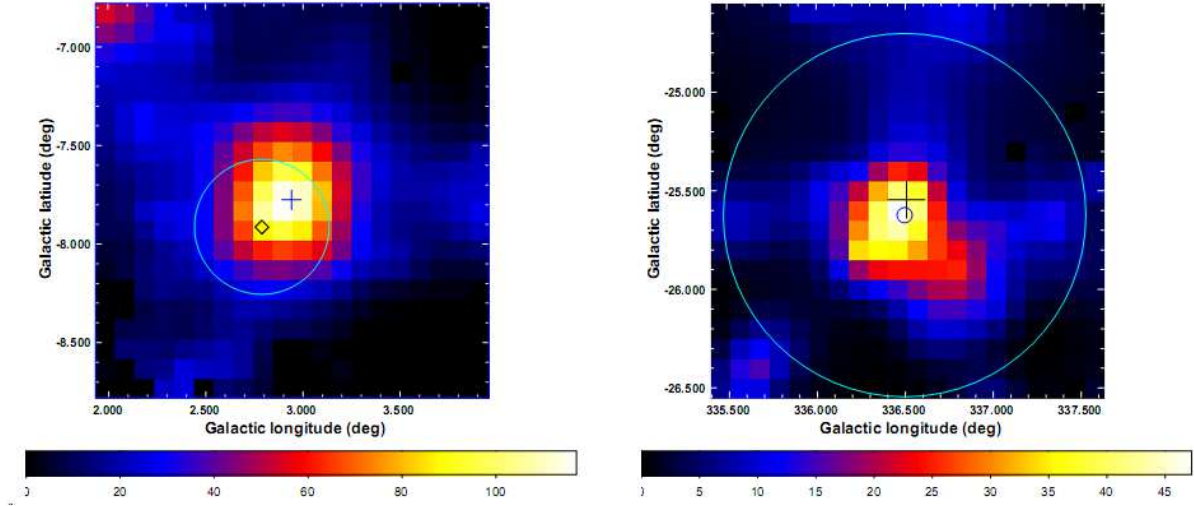


FIG. 3: The test-statistics maps of NGC 6624 (left) and NGC 6752 (right) [10]

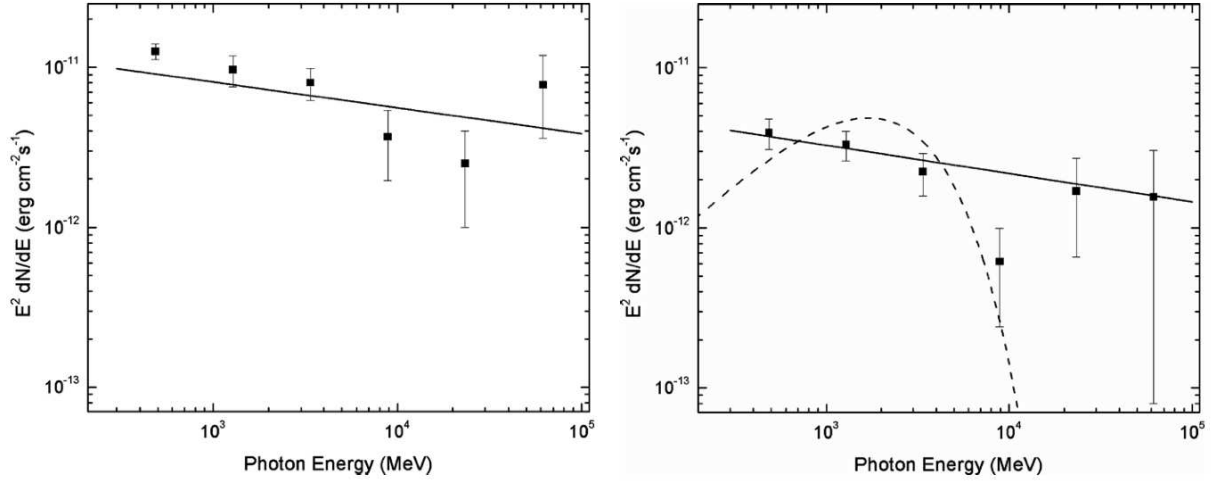


FIG. 4: Spectra of Liller 1 (left) and NGC 6624 (right). The solid and dashed lines represent the best-fit power law and power law with exponential cutoff, respectively [10].

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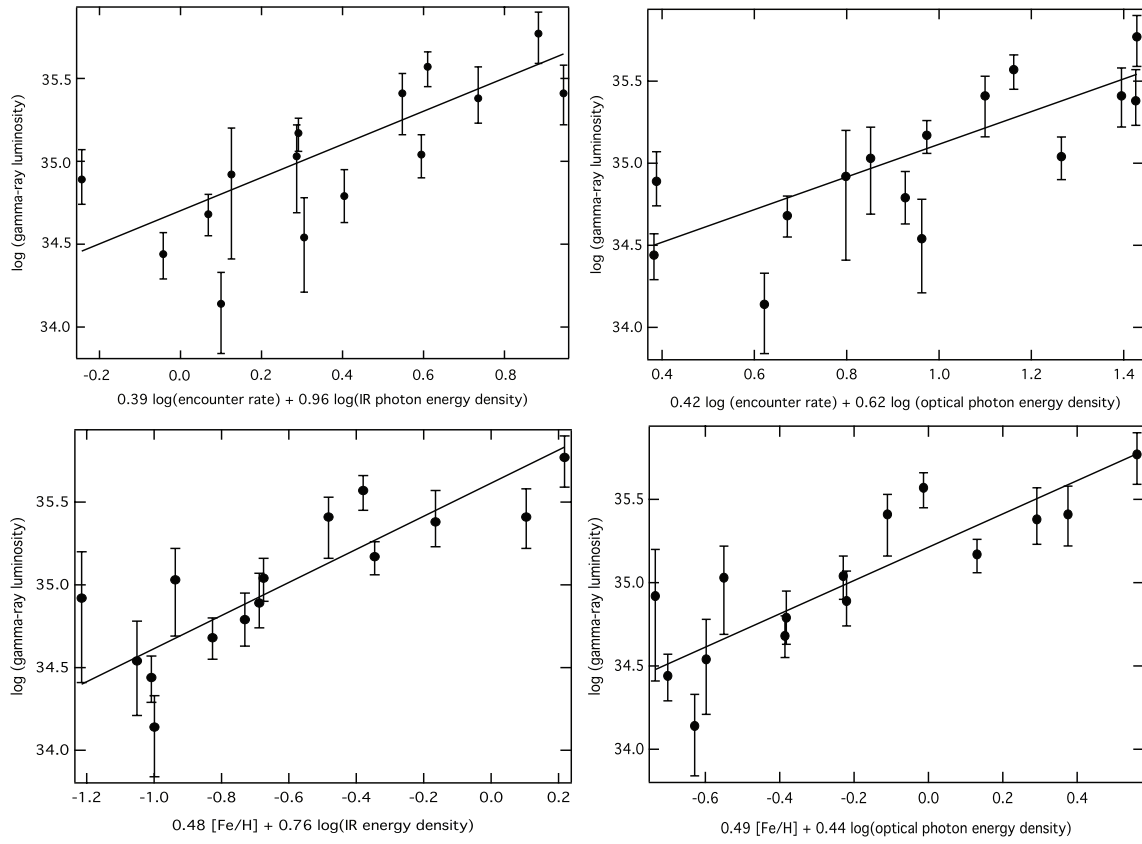


FIG. 5: The edge-on views of the fundamental plane relations of γ -ray GCs. The straight lines in the plots represent the projected best-fits [11].